MASTER IN OCCUPATIONAL SAFETY AND HYGIENE ENGINEERING

Dissertation presented in fulfillment of the requirements for the Degree of Master in Occupational Safety and Hygiene Engineering
Faculty of Engineering – University of Porto

PHYSIOLOGICAL INDICATORS OF FATIGUE

Jimena Ashur Pérez

Advisor: Professora Joana Cristina Cardoso Guedes – Universidade do Porto

Co-advisor: Professor Mário Augusto Pires Vaz – Universidade do Porto

Arguer: Amândio Manuel Cupido dos Santos – Universidade de Coimbra

President of the Jury: João Manuel Abreu dos Santos Baptista – Universidade do Porto

2017

Faculdade de Engenharia da Universidade do Porto

Rua Dr. Roberto Frias, s/n 4200-465 Porto PORTUGAL

VoIP/SIP: feup@fe.up.pt **ISN:** 3599*654

Telefone: +351 22 508 14 00 **Fax:** +351 22 508 14 40
URL: http://www.fe.up.pt **Correio Electrónico:** feup@fe.up.pt

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

.

1. INTRODUCTION

According to the ISO 6385:2004 fatigue is a mental or physical, local or general non-pathological manifestation of excessive strain, completely reversible with rest. Saito, K. [1] defines fatigue as a state of being tired, brought about by an excess of mental and physical work that can lower or impair human functioning.

In general, fatigue is a condition recognized as a decreased ability of individuals to perform activities at the desired level due to lassitude or exhaustion of mental and/or physical strength that is a concern of workers in many occupations throughout the world [2,3].

As stated in the definitions of fatigue given above, this complex phenomenon presents a mental and a physical aspect in the workplace, and it is the result of the combined manifestation of both lowered functions causing decrement enthusiasm for work as well as decrease in efficiency [1]. On the one hand, fatigue occurs frequently and generally comprises acute circumstance-based episodes that can resolve quickly after intervention such as rest or the improvement of an environmental stressor. On the other, at a more severe situation, it is less prevalent and potentially symptomatic of a more chronic and disabling condition such as major depressive disorder, fibromyalgia, or chronic fatigue syndrome [4].

It represents a workplace hazard because it affects the ability to think clearly and react appropriately. People who are fatigued might not recognize properly their own level of impairment, nor be aware that they are not functioning at their best. Fatigued workers are less alert, do not perform the same way as non-fatigued workers, are less productive and more likely to have accidents and injuries [5].

Causes and consequences of fatigue at workplace

According to U. Techera et al. [3], the causes of fatigue, among others, are the following:

- Sleep deprivation
- Mental exertion
- Muscular exertion
- Workload characteristics
- Overtime and long work hours
- Incomplete recovery
- At-Work environmental factors
- Social environment at workplace
- Emotional predisposition and distress

Sleep deprivation is considered probably the most common and significant cause of both physical and mental fatigue. Typically, sleep is compromised by early morning and night shifts [3]. Incomplete recovery refers to the process through which negative effects of mental and muscular exertion are reversed to return to a state prior to fatigue. Many individuals believe they can adapt to chronic sleep loss or recovery with only a single extended sleep episode, but these factors are more complex. According to The National Sleep Foundation's 2010 Sleep in America poll, one-fourth of the surveyed subjects indicated that their work schedule did not allow them to obtain adequate sleep and one-third reported that they did not obtain sufficient sleep to function at their best. What is more, more than one-third of the respondents surveyed indicated their quality of life has been affected in some way by sleepiness [6].

Among the studied causes of fatigue, the occurrence of overtime is also very common. This can be accomplished either by working more than 8 hours per day in a five-day-per-week schedule or by having fewer days off work per week. Long working hours also causes fatigue by exposing the individual to other at-work stressors such as noise, inadequate lighting, extreme temperatures, and other environmental and social factors, when present, for an additional period of time [7]. In Europe, about 20% of the working population experiences at least 5 hours of overtime weekly and 13% of the full-time employees in Europe work at least 10 hours of overtime a week [8].

In regard to social environment at the workplace, most of the working population spends one-third to one-half of their waking hours at work. This is why relationships with coworkers, managers, and subordinates play a major role in the development of mental fatigue [3].

In a study by Judith A. Ricci et al. [4] fatigue was associated not only with increased lost productive time, but also with reduced quality of life, which was significantly lower in workers with fatigue compared with workers without fatigue. Furthermore, they stated that the negative outcomes of fatigue do not only have safety consequences, but also economic. Workers with fatigue cost employers in the United States an estimated $136,4 billion per year in health-related lost productive time, an excess of $101,0 billion per year when compared with workers without fatigue. The majority of the excess cost was due to reduced performance while at work.

As for the consequences, fatigue can have several safety-related effects, including slowed reaction time, decrease balance and coordination, reduced vigilance, reduced decision-making ability, poor judgment, distraction during complex tasks, and loss of awareness in critical situations [9]. In his study about health effects of shift work and extended hours of work, Harrington [10] referred to this by highlighting that fatigue probably played a role in some of the major catastrophes (Three Mile Island, Chernobyl and the Exxon Valdez oil spill events) as they started in the early hours of the morning with errors by people who had been in the night shift. These people had been on duty for long hours, in a shift where the circadian rhythm is affected and when the levels of fatigue among workers are at their highest [3].

Reaction time of fatigued workers increased around a 24% when compared with well-rested workers. Furthermore, higher levels of fatigue induced by a second night without sleep resulted in around 57% increase in reaction time [11].

Relationships between causes and consequences are illustrated, empirically, in Figure 1.1. Dashed lines represent the inter-relationships among the causes and consequences of fatigue and solid lines represent the immediate relationships between causes, fatigue and consequences. Line thickness corresponds directly to the number of studies devoted to each relationship.

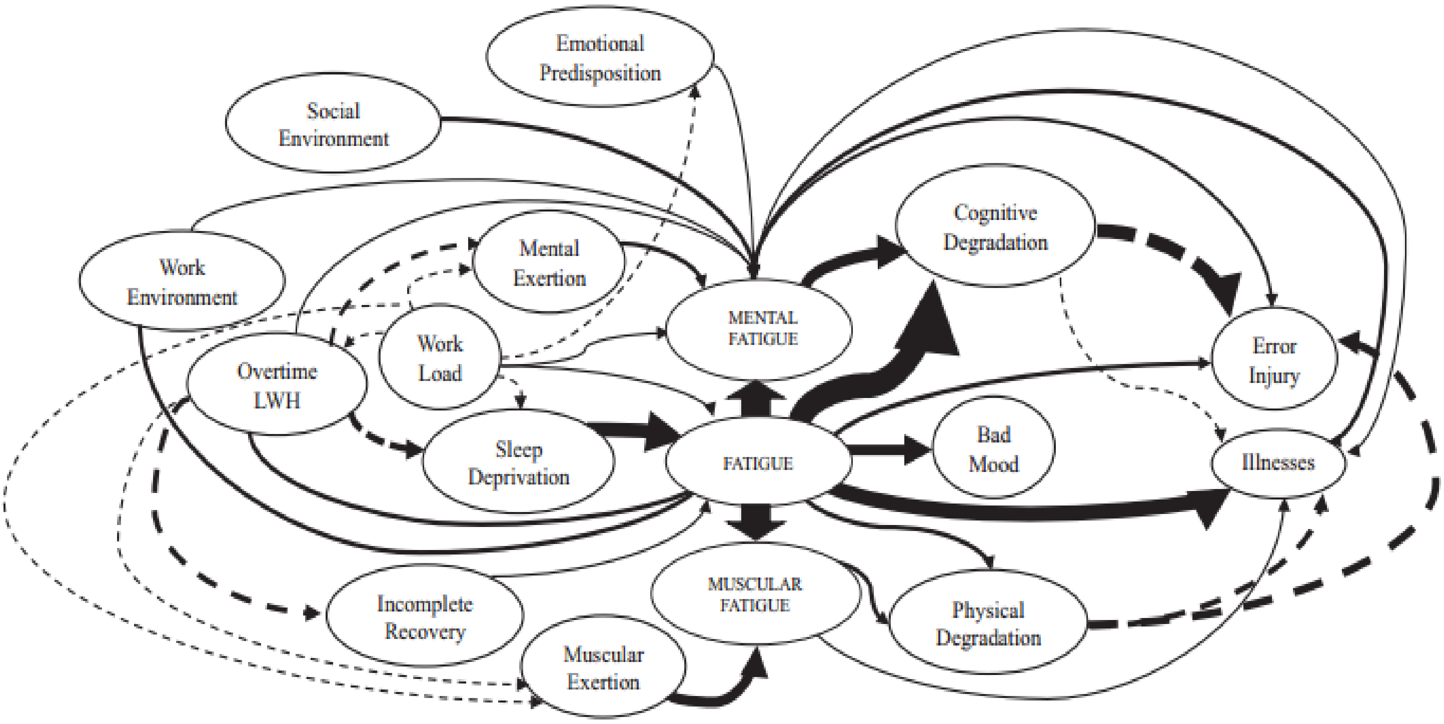

Figure 1.1. Systems model illustrating empirical literature on relationships among causes and effects of fatigue (3).

Relevance of studying fatigue at workplace

Data support that all of the complex cognitive functions are significantly deteriorated even with modest fatigue levels. Thus, it is not surprising that researchers have found evidence of a direct relationship between the degree of fatigue and rates of human error [3].

As previously stated when presenting causes and consequences of fatigue, fatigue-induced human errors can have major consequences for public safety, as well as for the workers involved. Taking all this into account, studying occupational fatigue gained importance, especially when connected to safety-sensitive works like healthcare professions.

For example, in nursing health professions work-related fatigue has been recognized as a source of adverse impact on quality of care, client satisfaction, and patient and nurse safety [12]. For nurses, work-related fatigue is often connected to working extended hours and short recovery periods. Under these conditions, they may experience cognitive, psychomotor, and behavioral difficulties that may lead slow reaction time, lapse in critical judgment, reduced motivation, and thus an increase in work errors. A study regarding nurses in Brunei public hospitals [13] showed that although a large proportion of the cohort reported adequate recovery between shifts, prevalence of chronic and persistent fatigue was still considerably high with a 30,3% of nurses affected by this condition.

Firefighting requires a range of cognitive abilities to complete specific work tasks becoming another well-known safety-sensitive profession. Grace E. Vincent et al. [14]

determined in their study that 43% of fire-day sleep periods were below 6h in duration, often occurring over successive days. In healthy, non-shift working populations, significant cognitive performance deficits equivalent to up to 2 nights of total sleep deprivation occur when consecutive night-time sleep opportunities are restricted to less than 6h [15], which means that in almost half of firefighters of the study, their abilities to perform a task safely decreased, increasing fatigue-related risks [16].

In addition, workers in high-control (high decisions) jobs were found to have a higher prevalence of fatigue than workers in low control jobs. It may be explained by the increased job stress that can come with a high-control job, linked to a higher prevalence of fatigue [5]. This responds to the profile of most safety-sensitive professions, as safety-sensitive workers are more likely to suffer stress due to the responsibilities associated to being alert most of the time. Otherwise, impaired performance, for whatever reason, could result in a significant incident affecting the health or safety of employees, customers, customers' employees, the public, property, or the environment [17].

As fatigue in the workplace has dual aspects, mental and physical, to evaluate them separately is impossible as they interact upon each other very closely [1]. This is why both psychological and physical approaches should be considered when assessing fatigue.

Psychological fatigue is understood as subjective meanwhile physical fatigue is considered objective. This last one can mainly be assessed through physiological parameters and subjective fatigue (psychological) through Borg's Rating of Perceived Exertion Scale (RPE) [18-21], which has remarkable value as a psychophysiological (mental and physical qualities) integrator [22].

To conclude, despite fatigue cannot be measured itself directly, its consequences can point out known symptoms, or at least physiological as well as psychological indicators relevant to these symptoms can be measured [1]. To this extent, it is important in the assessment of fatigue to take into account not only physiological but psychological measurements.

2. STATE OF ART

Assessment of fatigue through physiological indicators: a systematic review

Ashur Pérez, Jimena
UPORTO, Porto, Portugal

ABSTRACT: The aim of this review was to obtain relevant information about fatigue assessment through physiological indicators, in order to focus in a future on how it affects psychomotor skills and fine motor skills of workers. Four databases (SCOPUS, Science Direct, PubMed and Web of Science) were used to conduct a data search according to crosswords of keywords. Three phases were used: two phases using exclusion criteria (date, type of article, language, other - such as health condition or out-of-range age-, duplicates) and one phase using inclusion criteria (objective method of measurement, physiological parameters measurements - HR, oxygen levels, blood lactate-, non-static activity/work). The first phase outcome (125 articles) was reduced to 7 publications considered significant, that used physiological parameters such as HR, oxygen consumption and blood lactate, as well as subjective methods to measure physical exertion, mostly RPE scale. Some studies revealed strong correlations between RPE and both HR and blood lactate, and suggested that the best way to determine physical fatigue is through a combination of assessments, not a single variable measure. In the other hand, articles selected have demonstrated the significance of considering, besides physiological parameters, subjective perception of effort during a training process to determine fatigue. So, a further study should involve both objective and subjective measures to obtain more accurate results.

Keywords: physical exertion assessment, physical fatigue, RPE, HR, blood lactate

4.1 INTRODUCTION

2.1.1 *Work fatigue*

Work fatigue is a complex but well-known phenomenon, resulting from various factors, often linked to a feeling of exhaustion, lowering of physiological functions, and especially to a decrement in performance and work efficiency [1].

As stated in ISO 6385:2004, is a mental or physical, local or general non-pathological manifestation of excessive strain, completely reversible with rest.

2.1.2 *Fatigue measurement*

Despite fatigue cannot be measured itself directly, its consequences and some symptoms are known, or at least physiological as well as psychological indications relevant to these symptoms of fatigue can be measured. In this respect, fatigue (or so called physical exertion) can be understood through changes in physiological functions that include mental or nervous function, autonomic nervous function, endocrinological function, metabolism, etc. These functions are lowered, disturbed or broken down by excessive workload or effort and can be measured by physiological and biochemical techniques.

There can be mentioned a number of indicators which are generally applied in fatigue research: such measures representing cerebral cortical activity level as electroencephalography, channel capacity or perceptual threshold such as flicker fusion frequency, some indications of vegetative functions, biochemical variables relevant to metabolic changes or to endocrine regulation, motor skills and others. Those tests which have been advocated for fatigue measurement can be classified from the viewpoint of methodology into the following categories: questionnaires on subjective feelings of fatigue, psychological tests, neurophysiological tests, biochemical indexes, physiological tests, and autonomic nervous function tests [1]. In a further study, physical exertion in work environment (in this study work being professional hockey players) is expected to be evaluated through physiological indicators such as body temperature, blood lactate, heart and respiratory rate, along with movement analysis.

2.1.3 *Fatigue and fine motor skills*

There are studies that show, in different areas, that fatigue is in some way related to performance decrease. A study concerning health-care related workers showed that the level of fatigue is directly related to increased number of cognitive errors and decreased psychomotor efficiency and overall task performance [2]. Even if, in some cases, cognitive skills are more affected by fatigue than psychomotor skills, impeded cognitive performance may also lead to limited psychomotor proficiency.

Beyond that, it would be interesting to assess, particularly, the effect fatigue has on fine motor skills, above everything in the so called safety-sensitive professions (police officers, firefighters, health care providers, among others) as these occupations need the ability to accomplish tasks that require a combination of fine psychomotor and cognitive decision-making skills to provide safe effective services. Therefore, the decrement of fine motor skills due to fatigue in this kind of jobs will affect not only the workers but the safety of people to whom they provide services.

In this work, it is proposed to determine fatigue through physiological indicators that can lead to making decisions on whether workers are able to keep on performing efficiently and safely. On the other hand, the relationship between fatigue and the decrement of fine motor skills in professionals can be used to create tools that allow redesigning shifts and break hours in safety-sensitive professions.

Keeping this in mind, the main objective of this paper is the search of relevant information about fatigue evaluation mechanisms, with the aim to focus in a future on how it affects psychomotor skills in general and fine motor skills of workers.

4.2 METHOD

In this review, four databases were used to conduct a data search according to crosswords of keywords: SCOPUS, Science Direct, PubMed and Web of Science. Keywords were categorized in two groups: (A) with only two words, physical fatigue and exertion; and (B) with the words measurement, estimation and assessment. These keywords were selected after an initial search testing, in which the results, at first sight, reflected to be more related to the topic of interest.

Three phases were used in this research: two phases using exclusion criteria and one phase using inclusion criteria.

In some cases keywords of group (A) where searched in the titles, as results where wide for using the words to search into the entire article. This was the case of SCOPUS and Science Direct databases, as well as the three exertion keywords in Web of Science and PubMed databases.

A first phase of exclusion was carried out establishing eligibility criteria, in order to obtain significant results. The first criteria was “Date”: only articles from 2012 to 2017 were considered, except in those cases in which there were few articles or no article at all found in that period, thus the latest five years published that appeared were considered.

The second general criteria used was “Type of article”: only articles, articles in press and reviews were considered in this phase, although reviews were not considered later in the final results but as an extra useful complement.

“Language” was the third criterion, excluding all articles but those written in English or Spanish, while the fourth one was “Articles out of topic”. As this review is oriented towards ergonomics and it is planned to be included measurement of fatigue of professional hockey players, articles that came from medical sources (mostly journals) about diseases, disorders or just unrelated medical fields were excluded. In other words, all articles that were not from sources that included ergonomics, safety science, sports, sport medicine, sport science, motor skills and/or physiology fields were dismissed.

Lastly, a fifth eligibility criterion was named as “Other” to end the first phase of exclusion. In “Other” were included articles referring to diseases or in which participants had any medical condition (therefore considered not healthy) that have not been excluded before for coming from the approved aforementioned sources. Besides, when searching in Web of Science database, it was possible to dismiss some articles that at first sight showed to have a different approach that would not be useful for this research. In the other hand, articles about either young or elder subjects (not in the range of working-age people) were also excluded. All three aspects where included in the “Other” eligibility criterion.

In a second phase, duplicates were excluded by using a title filter to locate repeated articles. Furthermore, papers that are not directly related but serve as extra information were also dismissed (like the ones that do not address fatigue measurements per se but are still related to it in some way). In this phase also, now with fewer articles, remaining publications addressing diseases or out-of-range ages were excluded taking into account that these filters where applied before in title articles, and may have been left more with such characteristics that were not filtrated and needed more attention. Finally, it was possible to exclude articles (such as the ones about facial video-based detection of fatigue) that use a methodology that is not worth of attention for this study in which one of the main goals is physiological measurement.

The third and last phase consisted on the establishment and application of inclusion criteria among the selected articles. First, it was included all articles that use an objective method of measurement. In second place, based on these last results were included only those that measure physiological parameters of interest for this study (HR, oxygen levels, blood lactate). At last, from this latest outcome were selected publications in which the referred activity/work is non-static.

4.3 RESULTS

2.3.1 *General results*

By applying this methodology, it was possible to reduce the first phase outcome (125 articles) to 7 significant publications to this work.

In the first phase, considering the six combinations of keywords searched in the four aforementioned data bases, a total of 1.571 articles were rejected by date, 55 by type of article, 16 by language, 543 were out of topic and 172 filtered under the “Other” criteria (Table 2.1). It should be noted that as this work is health-oriented and physiological measures are involved, it is normal to have an outcome with a considerable number of articles referred to diseases, disorders or in which participants have a medical condition (considered out of topic). Furthermore, in this review were taken into account only the last five years of publications, so it was expected that a notable number of articles were to be excluded initially.

Table 2.1. Summary of the first phase of exclusión

Data Base	Total left	Summary of rejected articles				
		Date	TA *	L **	OT ***	Other
Scopus	58	565	28	13	168	32
Science Direct	24	435	9	0	234	38
Web of Science	25	296	16	2	99	24
PubMed	18	275	2	1	42	78
Total	125	1571	55	16	543	172

TA*: type of article; L**: language; OT***: out of topic.

After concluding the first phase of exclusion, 125 articles were identified, of which 53 were duplicates and were dismissed in the second phase, leaving a total of 72 articles.

When considering the criteria established on the second phase of exclusion as shown on Table 2.1, 24 articles were distinguished.

Table 2.2. Summary of second phase of exclusion

Filters order	Criteria	Filtered articles	Results after filters
1	Duplicates	53	72
2	Not directly related	33	39
3	Review paper	1	38
4	Out of range age and disease/disorder	11	27
5	Date	1	26
6	Non-relevant methods	2	24

The third phase, this time of inclusion, was carried out taking these 24 articles as basis. The first thing to consider was whether the publication was experimental or not. As all 24 were experimental, another criterion was used. There were 14 articles that use objective methods of measurement and, of those, were included 10 that measure physiological parameters of interest for this study (HR, oxygen levels, blood lactate). From this latest outcome were selected publications in which the referred activity/work is non-static (9 articles) and those in which the measurement of physical exertion is involved in their objectives, which left a total of 7 articles relevant to this work.

2.3.2 *Final result*

At last, seven articles (Table 2.3) were selected from all the research outcomes, after applying the three phases mentioned above.

Table 2.3. Articles selected

N°	Topic
1	Correlation between physiological variables and rate of perceived exertion during a water exercises classes
2	Heart rate, accelerometer measurements, experience and rating of perceived exertion in Zumba, interval running, spinning, and pyramid running
3	Relationship between subjectively perceived exertion and objective loading in trained athletes and non-athletes
4	Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity
5	Assessment of decision-making performance and in-game physical exertion of Australian football umpires.
6	A comparison of the impacts of continuous and interval cycle exercise on perceived exertion
7	Assessment of physical strain in younger and older subjects using heart rate and scalings of perceived exertion.

Table 2.4 shows the main characteristics of these articles, including aspects of the people that participate in the experiences, such as age range, mean age, sex and profession, among others. It also shows general features about the trials.

Table 2.4 Summary of principal characteristics of the selected articles.

Article	Participants	General characteristics
1	15 healthy women (18-25 yrs). University students who had participated regularly in WEC* for at least six months.	The WEC took place in a laboratory tank, with a cadence of 136 beats per minute (bpm). The protocol was defined taking into account that physiological variables (HR, VO2 and [Lac]) reach a steady state after 140 seconds of submaximal exercise.
2	35 subjects (22 females), students in academic sports sciences programs.	Four exercise sessions were carried out at the SIS Sports Center at the University of Stavanger, Norway: (a) Zumba (60'); (b) 4x4 running (45'); (c) 4x4 spinning (45') and (d) pyramid running (45'). Subjects were well nourished and consumed water during each session. Temperature around 22°C, humidity of 45%.
3	Elite-level short triathlon athletes from the Czech Republic (n = 23, 14 men and 9 women; mean age: 18,7 ± 1,78 years) and non-athletes who were students of the Faculty of Humanities at Charles University (n = 15, 9 men and 6 women; mean age: 19,5 ± 1,84 years).	The data were collected according to a graded exercise test using a bicycle ergometer. The test was performed under standard conditions on a Cyclus 2 laboratory device, which enables the use of an actual bike frame.
4	2.560 caucasian men and women (1.796 male, 764 female; age range between 13-83 years (mean age: 28 years).	All the participants performed a stepwise incremental exercise test until physical exhaustion (when they were not able to maintain pedal cadence ≥70 rev./min or were not able to run with the given velocity, and the HR was within ±10 bpm of age-predicted HRmax) on either a treadmill or an electromagnetically braked cycle ergometer.
5	15 Australian football umpires (Mage = 36, s = 13,5 years; Mgames umpired = 235,2, s = 151.3) from a regional Division 1 Australian football competition.	Hypothesis: decision-making performance would be negatively impacted by in-game physical exertion.
6	24 recreationally active, healthy students (12 males, 12 females, mean age ± standard deviation [SD] = 22 ± 3 years, mean body mass index [BMI] ± SD = 24 ± 4) from aUS university were recruited via email and word of mouth.	Participants completed five exercise trials in the laboratory performed on an electronically braked cycle ergometer.
7	Twenty-nine healthy non-smoking men aged 27–71 years (M=48, SD=15) representing three different age groups: 27-41 (10 participants), 42-56 (9 participants) and 57-71 years (10 participants).	Participants took part in 28 minutes of cycling with systematically increased and decreased load as well as in 7 hours of continuous cycling with low to medium exertion, interrupted by brief peak loads at high to very high exertion levels.

WEC*: water exercises classes

It should be noticed that all participants are healthy active people except from one study that also involves non-athletic persons in order to make a comparison.

In the other hand, information about the use of subjective scales of physical exertion measurement is presented in Table 2.5, along with the parameters that are measured (objective measurement) in each method of the seven articles. All articles but one use both subjective and objective methods to assess physical exertion. Among the subjective methods used in these publications, almost all use Borg's Scale. In regard to objective methods, 6 of the 7 articles measure heart rate, 4 blood lactate, some of them measure oxygen consumption and movement patterns.

Table 2.5. Parameters measured and type of subjective scale of the selected articles

N°	Subjective Scale	Parameters measured
1	Borg's Scale	Oxygen consumption (gas analyser); blood lactate concentration (lactometer); heart rate (HR monitor)
2	Borg's 15-point RPE	Heart rate (HR monitor); accelerometer counts (accelerometer)
3	Borg's Scale	Heart rate (HR monitor); blood lactate (lactometer)
4	Borg's Scale	Hart rate (surface ECG and ECG); blood lactate (enzyme-chemically measurement)
5	No	Decision-making performance (video-based test), in-game physical exertion (blood lactate levels) and movement pattern (global positioning system [GPS])
6	Borg's CR-10 Scale	Expired gases (metabolic cart); heart rate (HR monitor); blood pressure (by auscultation)
7	CP scale (Heller)	Heart rate (Varioport); chest electrocardiogram data recorded using disposable electrodes

4.4 DISCUSSION

Articles selected used physiological parameters such as heart rate (HR), oxygen consumption and blood lactate, as well as subjective methods to measure physical exertion, mostly Borg's Rating of Perceived Exertion (RPE) scale. RPE is a widely used and proven valid psycho-physical tool to assess subjective perception of effort during exercise [3].

It is well known that in healthy subjects, strong relationships exist between RPE and heart rate during physical activity (1 RPE point is approximately 10 bpm) [4]. Kjell Hausken et al. [5] found that in Zumba exercise session, a very dynamic exercise, subjects had a significant correlation of 0.5-0.6 between rate of perceived exertion (RPE) and percentage of maximum heart rate (%HR max), which encourages to keep on exploring this relationship to determine physical fatigue, despite the fact this relationship was not found in other activities evaluated, as spinning.

Also, Johannes Scherr et al. [4] found a strong relationship for the entire cohort between RPE and blood lactate (even higher than between HR and blood lactate) and between RPE and HR. In their study, individual's subjective overall perception of muscle fatigue and physical stress was assessed alongside objective measures of lactate and HR. These high correlations between RPE and both HR and blood lactate indicate the high precision of the predictive value of these objective measures of intensity (HR or blood lactate) as a function of RPE.

What is more, Olkoski et al. [6] found a correlation between oxygen consumption and both heart rate and blood lactate, which is important as Scherr et all.[4] demonstrated to be a strong association between HR and blood lactate with RPE; so this could imply there is also a relationship between oxygen consumption and RPE that can be studied and considered in further studies.

Larking et al.[7] studied the influence of in-game physical exertion over decision-making performance. The study concluded that physical strain may not affect decision-making performance. This provides useful information for the study, as decision-making is a cognitive skill, and even if, in some cases, cognitive skills are more affected by fatigue than psychomotor skills, impeded cognitive performance may also lead to limited psychomotor proficiency, that is what a further study pretends to approach.

On the other hand, Kovářová et al. [8] determined that the model of the subjective perception of fatigue does not lend itself to objectivization. They detected through a cubic model, a significant association between heart rate and the Borg Scale of Fatigue score in a non-athlete group (69%) but not in an athlete group (40%). Therefore, they suggest that for non-athletes, the Borg Scale may be used as a tool for the objectivization of physical loading as evaluated by heart rate, but not for elite endurance athletes, for whom the most predictive parameter would the blood lactate level. In any case, the relationship should still be considered, as the study will be oriented to workers in general and not only to elite endurance athletes (in the case of professional athletes who do the activity for a living).

Nadine Kakarot et al. [9] revealed in their results that, while both measurements are suitable to capture physical strain, HR is not as specific as PE. Although this may be true in some activities, it is considered worth analyzing the relationships in more depth.

To sum up, there is information that supports the use of physiological parameters to determine physical fatigue, but always along with the subjective measurement of perceived exertion.

4.5 CONCLUSIONS

The data reveal that the relationships between RPE and exercise intensity (assessed by blood lactate, and heart rate) are very strong and independent of age, gender, medical history, level of physical activity and exercise modality [4]. This marks a startpoint for the further assessment of fatigue that this work pretends.

According to Borg [3], an integration of central factors such as HR, oxygen consumption and blood lactate, would explain better the psychophysical variation tan any single physiological variable. This suggests that the best way to determine physical fatigue is through a combination of assessments, not a single variable measure. Nevertheless, articles selected have demonstrated the significance of considering, besides physiological parameters, subjective perception of effort (perceived exertion) during a training process to determine physical fatigue.

Taking this into account, further studies should involve both objective and subjective measures to obtain more accurate results.

4.6 REFERENCES

1. *Measurement of fatigue in industries.* **Saito, Kazuo.** 1999, Industrial Health: National Institute of Occupational Safety and Health, pp. 134-142.

2. *Effect of fatigue on psychomotor and cognitive skills.* **Kanav Kahol, Ph.D., et al., et al.** 2008, The American Journal of Surgery, pp. 195–204.

3. *Psychophysical bases of perceived exertion.* **Borg, Gunnar A.V.** 5, 1982, Medicine and Science in Sports and Exercise, Vol. 15, pp. 377-381.

4. *Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity.* **Scherr, et al., et al.** 2013.

5. *Heart rate, accelerometer measurements, experience and rating of perceived exertion in Zumba, interval running, spinning, and pyramid running.* **Hausken, K. and Dyrstad, S.M.** 2013.

6. *Correlation between physiological variables and rate of perceived exertion during a water exercises classes.* **Olkoski, M., et al., et al.** 2014.

7. *Assessment of decision-making performance and in-game physical exertion of Australian football umpires.* **Larkin, Paul, et al., et al.** 2014.

8. *Relationship between subjectively perceived exertion and objective loading in trained athletes and non-athletes.* **Kovářová, L., et al., et al.** 2015.

9. *Assessment of physical strain in younger and older subjects using heart rate and scalings of perceived exertion.* **Kakarot, Nadine and Müller, Friedrich.** 2014.

3. DEFINITION OF OBJECTIVES AND METHODOLOGY

The main objective of this work was to assess fatigue through physiological indicators. It was expected to create a model that allows determining fatigue related to perceived exertion (subjective method) by physiological parameters (objective method) like heart rate (HR), blood lactate (LAC) and core temperature (CT). This model is pretended to serve as a start point to study the influence of fatigue on performance that may allow later to redesign shifts and break hours especially in safety-sensitive professions.

To this purpose, nine players of a Portuguese rink hockey team were invited to participate in the experience. It was decided to run the tests using this cohort because of their physical conditions and abilities to perceive exertion.

As they are athletes used to training more than 6h per week, they are familiarized with sensations and symptoms of fatigue and can recognize their maximum levels of intensity when training. This is important at the moment of creating a model that pretended to relate physiological variables to perceived fatigue, because the physical strain they experienced during the test had to be recognized and transmitted as accurately as possible; so, their athletic condition and habit of working with their bodies made them a good testing sample.

Thereby, measurements of HR [20], LAC [23-25] and CT [26-29] were taken following a specific protocol created based on the intermittent nature of the sport (using sprints) [30]. Along with these measurements, perceived exertion values were registered using Borg's Rating of Perceived Exertion Scale (RPE). After the test, data were processed and information of the physiological parameters was used to analyze a relationship with RPE. The model can predict values of RPE trough objective indicators of fatigue, resulting in a psychophysiological integration of parameters.

The complete experience is presented in the article that follows in Chapter 4.

4. FIELD STUDY

PHYSIOLOGICAL INDICATORS OF FATIGUE IN RINK HOCKEY PLAYERS

Ashur Pérez, Jimena
UPORTO, Porto, Portugal

ABSTRACT: The main goal was to determine the relationship of blood lactate concentration (LAC) and core temperature (CT) to fatigue in rink hockey players. Nine male athletes from a Portuguese rink hockey team, playing either in forward or defense positions, participated in the experience. Subjects performed a series of sprint cycles of approximately 78m divided in three parts, ending with a shooting to the goal. After each shot, players had around 30s to rest before starting a new cycle, repeating this routine over 6 times or until exhaustion. CT was recorded continuously, while LAC was registered at rest and immediately after each lap ended, at the same moment rating of perceived exertion (RPE) was recorded. Heart rate (HR) was also measured but due to signal noise it was not used to evaluate fatigue in this study. It was necessary to transform LAC and CT data into variations to create a scale that would allow prediction of fatigue through the combination of both parameters. A multiple regression model demonstrated that fatigue related to perceived exertion could be predicted by a direct relation to LAC and CT variations and also an inversely proportional relation to a CT variation polynomial function (grade 2). This model accounted for the 96% of the total variance and low standard error. The significant correlation of Borg's RPE Scale to the physiological parameter suggested that it may be used as a tool to objectively determine fatigue of rink hockey players when evaluated jointly through variations of CT and LAC.

Keywords: heart rate, blood lactate, core temperature, rating of perceived exertion, fatigue, rink hockey

Abbreviations

RPE: Rating of Perceived Exertion
HR: Heart rate
LAC: Blood lactate concentration
CT: Core temperature

4.1 INTRODUCTION

4.1.1 *Rink Hockey*

Rink hockey is played with two teams of five players (one goalkeeper and four skaters) on a rink of 20 x 40 meters with a wall around its perimeter.

A team can have a maximum of ten players, including a back-up goalkeeper, which means that substitutions are frequent. Rink games are played in two halves of 25 minutes each with a ten-minute half-time break [1], but its total time including pauses is approximately 70-80 minutes and sometimes more [2]. It is a sport of an intermittent character with incomplete recoveries. Mostly, playing times do not exceed 30 seconds due to interruptions (infractions or of regulatory nature). The most frequent movements are those of low intensity, since players are accustomed to regulate their efforts to stay on the game, as well as those of high intensity, since they are the ones that make the difference and allow creating dangerous and decisive situations in the game (counterattacks, overcoming a defender, goal opportunity, etc.) [3].

It requires speed, technique and strategy. Because roller hockey is a power sport, players must be in excellent physical condition and have good cardiovascular capacity and superior reflexes [4].

According to the results obtained by J. Merino Tantiña et al. [3], a roller hockey resistance training should be intermittent and iterative, with a working time between 1-50 seconds contemplating displacements from 1 to 20 seconds at different intensities (low, medium and high), and with pauses of 1 to 30 seconds. This way, considering these conditions, high intensity displacements (sprints) are taken into account for this study, with the intention of testing the players in a similar condition as the aforementioned determinant game situations.

4.1.2 *Fatigue*

Fatigue is a complex but well-known phenomenon, resulting from various factors, often linked to a feeling of exhaustion, lowering of physiological functions, and especially to a decrement in performance and work efficiency [5].

In the sport field, fatigue may be defined as the onset of a condition of organic and functional exhaustion involving a drop in an athlete's ability to perform [6]. The term exercise-induced fatigue may be used to describe a sensation (to tire), a system failure or physical reduction in exercise performance, and also their associated physiological, biomechanical, and biochemical events [7].

4.1.3 *Fatigue measurement*

'Fatigue' is commonly used in a number of disciplines in order to explain system failure and associated physiological, physical, biomechanical, and/or cognitive events and their related sensations or perceptions. As a result, scientists have formed a number of linear models to place a causal link between these events and their feelings [7].

Despite fatigue cannot be measured itself directly, it can be understood through changes in physiological functions, which are lowered, disturbed or broken down by excessive workload or effort and can be measured by physiological and biochemical techniques. Fatigue measurement tests can be classified into questionnaires on subjective feelings of fatigue, psychological tests, neurophysiological tests, biochemical indexes, physiological tests, and autonomic nervous function tests according to the methodology [5].

Since it is a concept that is related to objective and subjective dimensions, its evaluation and determination must be carried out in the same way, contemplating also both objective and subjective methods. To this purpose, physical exertion of rink hockey players is evaluated jointly through physiological indicators such as core temperature (CT) and blood lactate concentration (LAC), always related to Borg's Rating of Perceived Exertion (RPE) Scale [8-11].

4.2 MATERIALS AND METHODS

4.2.1 *Participants*

The research sample consisted on nine male athletes from a rink hockey team of Porto, who play either in position of forward or defense. The inclusion criteria were athletes without any medical condition and not taking any medications.

Participants ages were between 15 and 33 years old, with a group mean (±SD) age of 21 ± 5,29 years old, height 178 ± 8,85 cm and body mass 74,09 ± 12,14 kg.

The study was submitted to the Ethics Committee (CEUP). All players were advised about possible risks and benefits of the study, as well as they were informed about the questionnaire required before the tests in order to collect relevant information. A written informed consent was obtained from those subjects willing to participate in the experience.

4.2.2 *Materials and equipment*

The RPE Borg's Scale [8-11] was used to subjectively determine fatigue.

Meanwhile, fatigue was intended to be determined objectively through the relation with some parameters such as heart rate (HR), CT and LAC.

LAC was determined by blood samples (collected at rest and the end of each cycle) analyzed with Lactac_Pro. The other two parameters were registered through Equivital Life Monitor equipment, a "wear and forget" system type. For core temperature determination, an ingestible temperature sensor was used [12].

Additionally, circuit times were measured using chronometers, and filmed using a GoPro.

4.2.3 *Experimental design*

There are many studies that use ingestible sensors to measure core temperature in a practical and accurate way in the sport field [13-16]. In this study, core pills were used to monitor internal temperature during the test. This way, the day before the experience, players were given core pills to take at least 8-10 hours before the test. These pills provided core temperature of each athlete during the entire test, synchronized with the equipment used to measure other parameters (Equivital).

Before starting the test, athletes were explained the circuit and what does the RPE Borg's Scale consist on. They warmed up first and one by one were assisted to put on the equipment (Equivital), which measured HR, breathe rates and movement analysis parameters.

While they were preparing to start, a short questionnaire was asked to each one of them regarding personal information such as age, height, weight, diet habits, water consumption, training hours, etc.

Athletes wearing full hockey equipment (including the stick) were asked to perform series of sprint cycles (represented on Figure 4.1) of approximately 78m divided in three parts that ended with a shot to the goal. After each shot, players had to rest around 30s before starting a new cycle [3]. This cycle was meant to be repeated over 6 times, or until exhaustion [17,18]. Only after a player had completed the test, another started.

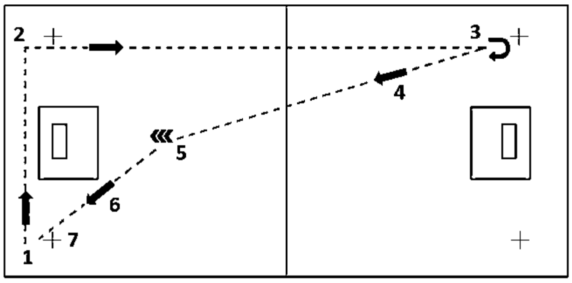

Figure 4.1. Test circuit- **1**-Starting point; **2**-Sprint to the opposite side of the court; **3-**Inversion; **4-**Sprint to shooting position; **5**-Shot; **6-**Back to starting point; **7**-Lactate test.

Blood samples were obtained from earlobes for LAC analysis at rest, to determine the basal estate in point N°1 (Figure 4.1), and at the end of each lap during the resting time [19-21]. Then, players had to sprint to the opposite side of the court through the 2-3 track. In the point N°3 they had to make an inversion and sprint to point N°5 (shooting position), where the balls were passed by the coach so players could shot to the goal. Immediately after the shot, players had to return to the starting point where they had to indicate their fatigue level according to the RPE Borg's Scale. From the moment they arrived to the starting point they had about 30s to rest, while the blood lactate sample was obtained before starting the cycle again.

The cycle was repeated until the subject considered he could not continue anymore.

4.2.4 *Statistical analysis*

All data were analyzed using IBM SPSS Statistics version 24 and XLSTAT 2017. A Cronbach's alpha reliability test was run to assure the consistency of the measurements. Shapiro-Wilk test was used to analyze normality of the data obtained through this experience, using a significance of 0,05. Finally, it was used multiple regression in order to explain perceived fatigue through physiological parameters. Graphical analysis was performed with Microsoft Excel 2010.

4.3 RESULTS

4.3.1 *General results*

For the parameters included in this study (LAC, CT and HR) consistency was proved obtaining a Cronbach's alpha $\alpha>0,70$.

Shapiro-Wilk test confirmed non-normality of the data ($p<0,05$). Due to the non-normality distribution of the data, results presented by player will show the trend of the parameters related to RPE Scale, but no further statistical analysis was made. Nonetheless, data was transformed into LAC and CT variations proving to follow a normal distribution (Shapiro-Wilk test, $p>0,05$) and enabling, in this way, to make a statistical approach through a multiple regression analysis.

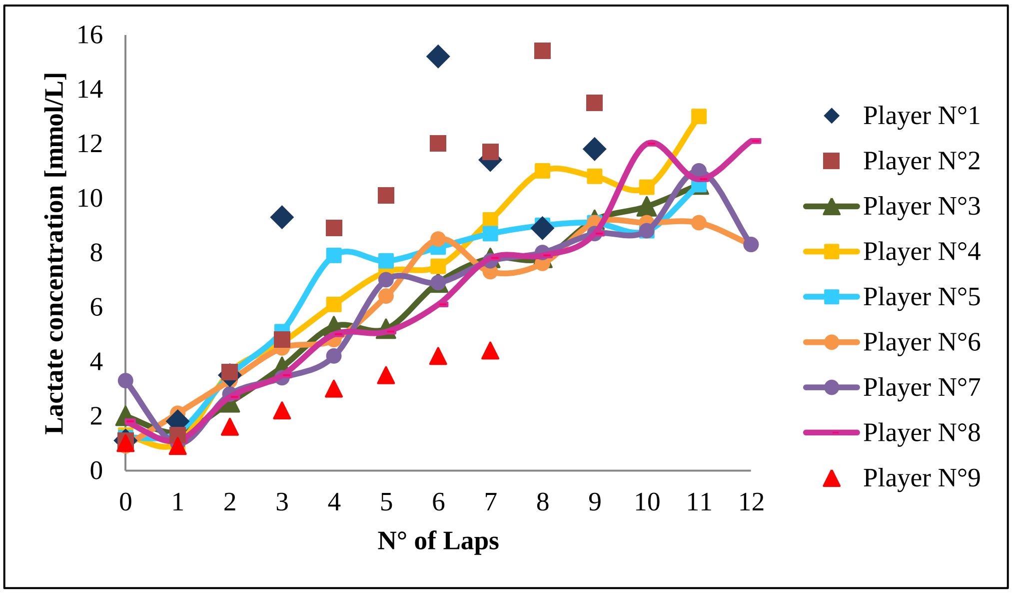

Figure 4.2. Lactate concentration behavior over number of lap per player.

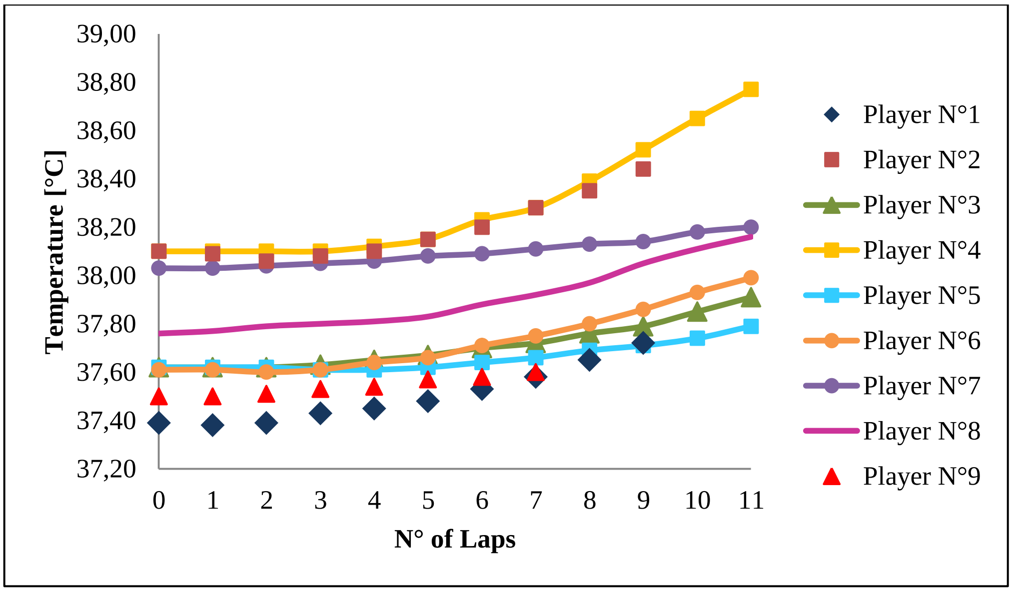

Figure 4.3. Core temperature behavior over number of lap per player.

LAC

Results of LAC are presented in Figure 4.2 related to the number of laps that each player completed. The highest values were clearly found for Players N°1 and 2, and the lowest for Player N°9. The rest of the subjects presented values around 1-2mmol.l^{-1} for the first lap and 10-13mmol.l^{-1} for the last ones.

CT

CT behavior over number of laps per player is graphically represented in Figure 4.3. Maximum differences of temperature increase were observed in Player N°4 (0,67°C), and the lowest in Player N°9 (0,10°C).

HR

Table 4.1 shows mean HR and standard deviation per lap calculated using HR lap average of each player after eliminating values under 70bpm and over 220bpm.

Table 4.1. Mean (±SD) HR of all players per lap.

Lap	HR (±SD) [bpm]	Lap	HR (±SD) [bpm]
1	152 (± 30,04)	7	189 (± 12,22)
2	174 (± 23,81)	8	185 (± 13,74)
3	187(± 26,64)	9	196 (± 15,91)
4	181 (± 18,75)	10	192 (± 14,18)
5	184 (± 21,70)	11	185 (± 31,13)
6	191 (± 15,86)	12	181 (± 36,14)

Despite HR data exhibit a Cronbach's alfa α=0,719 (>0,70), they presented overmuch noise hence low quality, resulting in erroneous and undesirable frequencies even with filters. Moreover, it is known that normal and both maximum and minimum heart rate can vary substantially from one person to another, even at the same physical condition [19,22]. Taking the aforementioned into account, it was considered that in order to analyze variables as intended (using all the values per lap and not per player), HR data should not be considered as they might explain properly each player behavior individually, but not as a whole which is the main objective of this work. Therefore, HR data will not be included in the model that pretends to explain perceived fatigue through physiological parameters.

4.3.2 *Results by player*

Figures 4.4, 4.5 and 4.6 graphically represent variations of CT and LAC per lap for Players N°1, N°2 and N°9 respectively. These three players presented different outcomes compared to the rest, therefore were analyzed separately.

The rest of the sample, Player N°3 to N°8, follow a similar growing trend for both LAC and CT that can be observed in Figures 4.2 and 4.3 respectively. A similar tendency was expected and corroborated for LAC and CT variations per lap for this group, giving a start point to analyzing their joint relationship with RPE.

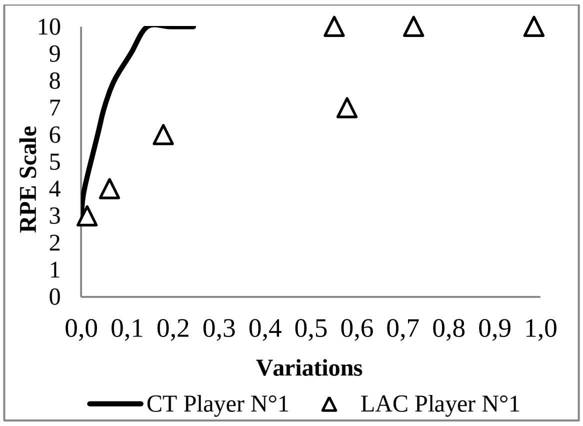

Figure 4.4. Variations of CT and LAC per lap over RPE Scale for Player N° 1.

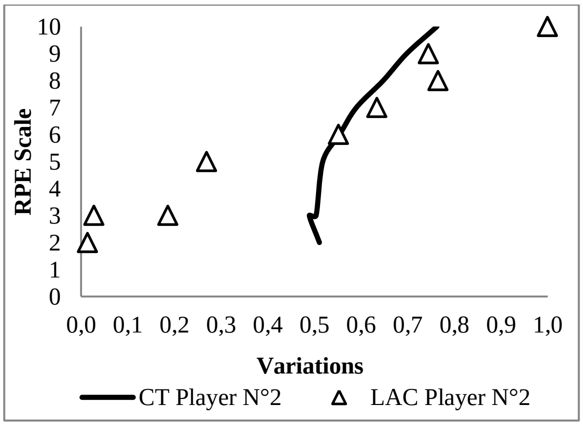

Figure 4.5. Variations of CT and LAC per lap over RPE Scale for Player N° 2.

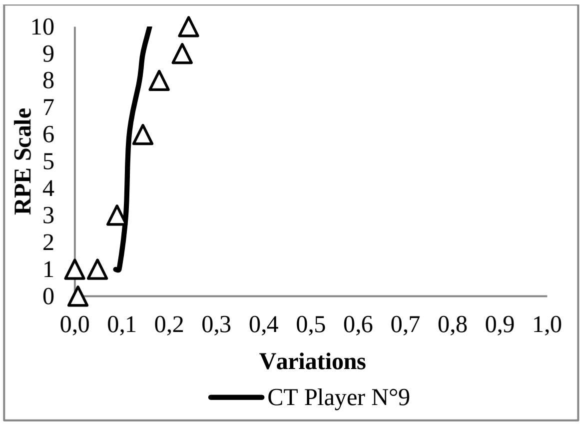

Figure 4.6. Variations of CT and LAC per lap over RPE Scale for Player N° 9.

4.3.3 *Multiple regression model*

A multivariable regression was used in the attempt to explain perceived fatigue through variations of LAC and CT, obtaining a significance $F=1,4283.10^{-51}$ (<0,05). LAC and CT data were transformed into a new scale (using variations: $x-x_{min}/x_{max}-x_{min}$) which allowed the analysis of RPE as a function of both parameters.

Parameters of the regression are shown in Table 4.2.

Table 4.2. Parameters of multiple regression model.

	Coefficients	Standard Error	P-value
Intercept	0	-	-
LAC	11,2116	0,4080	$8,765.10^{-37}$
CT	3,3480	1,1918	0,0066
CT^2	-5,1436	1,4356	0,0007

The model, which used data of the eleven laps that Players N°3 to N°8 had in common, is represented by Equation 1 (R^2=0,96 and S=0,96). Figure 4.7 shows graphically both predicted and real values of perceived fatigue.

$$RPE = 11{,}2116 * LAC + 3{,}3480 * CT - 5{,}1436 * CT^2 \qquad \text{(Equation 4.1)}$$

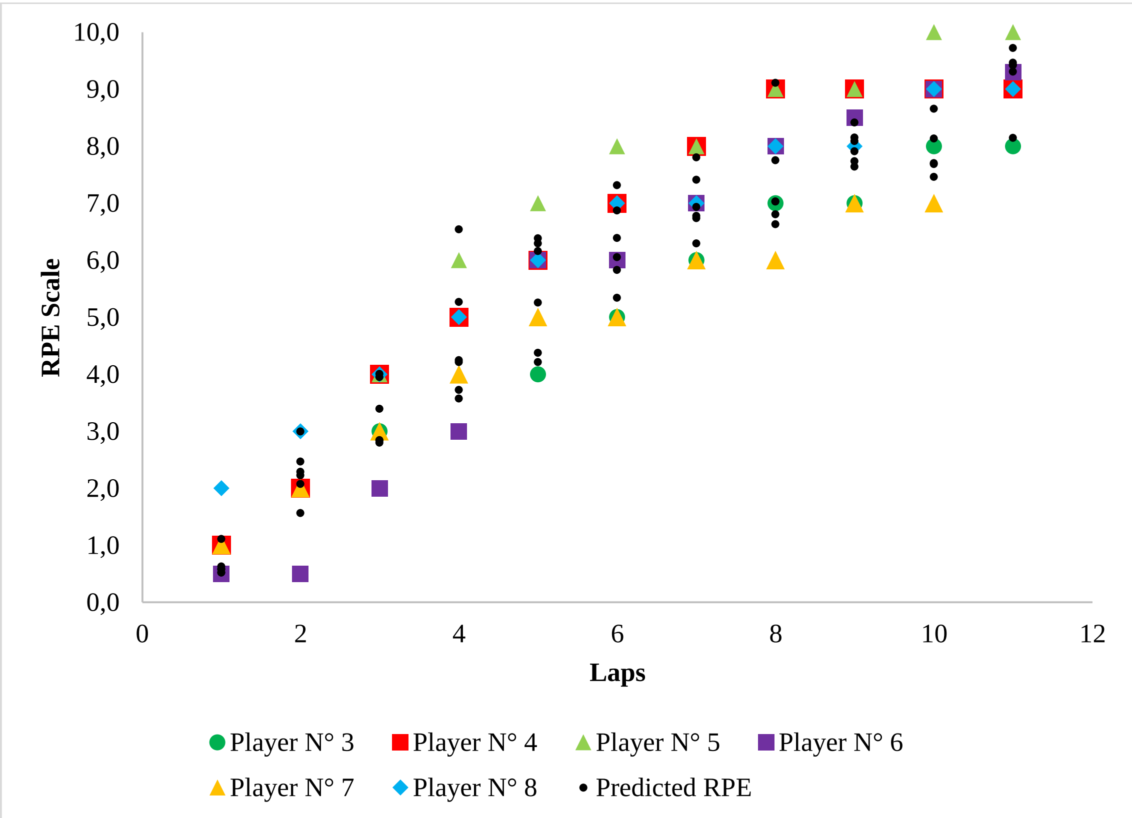

Figure 4.7. Multiple regression model: predicted values of perceived fatigue and real values of RPE per lap.

4.4 DISCUSSIONS

4.4.1 *General results*

As expected, blood lactate concentration increased as it was perceived a higher level of fatigue in the scale (Figure 4.2), gained with each subsequent repetition.

From all nine subjects, six felt like they had reached their maximum level, which corresponds to a 10 value in the RPE Scale.

Lactate concentration increased following a trend with maximum values between 9-13 mmol.l^{-1} in most players except for Players N°1, 2 and 9. Similar values were also observed by Bangsbo [23] in elite level soccer matches, where individual values of blood lactate concentration frequently exceeded 10 mmol.l^{-1} during the match after high-intensity situations. Differences with Players N°1, 2 and 9 can be explained as they were considered outliers after the test, due to a protocol deviation in the case of Player N°1 and 2, and inadequate conditions to meet the objectives of Player N°9 (lack of appropriate resting, eating and hydration in the last three days and a probable state of hypoglycemia). Following this, it can be observed that Player N°9 reached its level of exhaustion (10 in RPE Scale) sooner than the rest of the subjects, with a low lactate value (4,40 mmol.l-1) which insures that fatigue was reached in his case because of non-normal conditions.

It was also found that, as predicted, internal temperature incremented along with perceived fatigue, according to RPE Scale (Figure 4.3). The differences observed between core temperatures at 0 RPE values (previous starting the test) can be physiologically explained, since average core temperature can vary from person to person and the core pill taken to measure internal temperature can be allocated in different zones in the stomach. Nevertheless, discrepancies (always less than 0,70°C) are not significant, considering these are subjects that had already done a warm up.

4.4.2 *By player*

Despite exhibiting that perceived fatigue presented an increasing tendency along with the variations per lap of both parameters, Players N°1 and N°2 showed the highest lactate variations (values of 1 in Figures 4.4 and 4.5), far from the values exhibited by the rest of the subjects. Hence, the trend is always growing, but still significantly different from the rest of the players for this work’s purpose.

On the other hand, Figure 4.6 shows that Player N°9 had very low variations (below 0,25), corresponding to a RPE value of 10 reached rapidly in7th lap, unlike the rest of the group that only achieved their maximum level on the 10th lap or more (variations of 0,50-0,78; two or three times more).

It is evident that these three players represent especial cases in this study as stated above. Considering this, subjects were reduced to a sample of six for analysis, excluding the three outliers for the reasons aforementioned. Variations of CT and LAC of Players N°3 to N°8 (in the same scale) present a perceptible relationship that may explain perceived fatigue.

There are some studies that show association between RPE Scale and HR or LAC in exercise [24,29] but no studies were found that relate more than one parameter, let alone were found studies in which perceived exertion is explained, besides lactate concentration, by core temperature. To this extent, relationship of both parameters with RPE Scale was studied through a multiple regression model.

4.4.3 *Multiple regression model*

As a result of the existence of the outliers, the sample was reduced to six players (from N°3 to N°8) and only data from the eleven laps they had in common were used in order to reach homogeneity (data from the 12th lap of Players N°6, N°7 and N°8 were excluded), a total of 66 measurements for each variable.

It was necessary to transform data into the same scale so their effect in RPE could be analyzed properly. For this transformation, variations of CT and LAC were used as stated above.

Five models were used to study relationship between RPE and physiological parameters. They included a direct relation with LAC and a more complex one between RPE and CT variations, as it is not directly proportional but has instead a polynomial relationship that can be observed in Figure 4.3. In order to analyze the data using multiple regression models, it was necessary to simulate this polynomial relation with a third and fourth variable calculated as the square and cube of CT variation.

From the five models described RPE as function of physiological parameters variations (some with one variable and some with variables combined), the one that used the three combined variables (LAC, CT and square CT variations) appeared to be optimal as it showed that correlations were meaningful (Sig. F<0,05) and that all variables influenced RPE (p<0,05). This model also showed the highest and lowest R^2 and SE (Table 4.3) compared to the rest, except for LAC/CT/Square CT/Cubic CT model that has a slightly lower SE; but as this difference is only 0,06 and the model presented almost the same determination coefficient it was discarded for being more complex (polynomial function of grade three versus a grade two) without significantly improving the fitting of the model.

Table 4.3. Regression models statistics.

Model*	P-value (Comparison to α=0,05)	Sig. F (Comparison to α=0,05)	Adjusted R^2	SE
LAC	<0,05	<0,05	0,87	1,00
LAC/CT	>0,05	<0,05	0,96	1,05
LAC/CT/ Square CT	<0,05	<0,05	0,96	0,96
Square CT /CT	<0,05	<0,05	0,70	3,45
LAC/CT/ Square CT/ Cubic CT	<0,05	<0,05	0,96	0,90

*Represented by variations of the parameters

This way, the optimal model presents a direct relation of RPE with LAC and CT variations but also an inversely proportional relation with this last parameter that emulates the second grade polynomial function.

Equation 4.1 represents the multivariable model mathematically, which explains RPE through LAC and CT variations in this study, accounting for the 96% of the total variance. The coefficient of determination obtained (R^2=0,96) is significantly higher than those found in previous studies of the relationship of RPE and LAC or HR [19,24]. The standard error (SE=0,96) also showed that perceived fatigue can indeed be significantly predicted from lactate concentrations and core temperature increases through this model for rink hockey players, as it exhibits a low value (0,96 in a scale of 0-10).

Figure 4.7 shows that values of RPE obtained with LAC and CT variations are very well predicted since they are comprehended in the same range of the real values of RPE obtained from each player per lap and follow the same evolution.

4.5 CONCLUSIONS

This study allowed identifying a significant correlation of Borg's RPE Scale to the physiological parameters LAC and CT. To this extent, RPE Scale may be used as a tool to objectively determine physical strain of rink hockey players when evaluated jointly through variations of CT and LAC. As it was demonstrated, the multiple regression model can predict RPE values objectively (through the physiological parameters) with a determination coefficient of 0,96, which means that 96% of the data can be accurately predicted by this model.

4.6 LIMITATIONS AND PERSPECTIVES

Despite the strong relationships found, the current study has certain limitations. To begin with, the sample was small and data were non-normally distributed. This was overcome by the need of data transformation into variations to continue the analysis due to the different scales of the parameters, being these new variables normally distributed. Nevertheless, in a future it should be considered to analyze a larger cohort.

On the other hand, participants were physically active people, with more than 6h of training per week that did not have any medical condition nor consumed medicaments. Also, at the moment of the test, they were well rested, hydrated and had been following a normal diet.

From this objective model of prediction of fatigue through LAC and CT, performance of players can be analyzed in a future in order to recognize at which point of the RPE Scale (level of fatigue) it begins to be affected. Thus, this study could establish the basis for the development of a game management tool with real time monitoring of each player, for the prediction of maximum performance and fatigue limits of each athlete, as well as estimation of replacements needed.

As stated by J. Merino Tantiña et al. [3], rink hockey is a sport of an intermittent nature with incomplete recoveries; therefore, practices should not only focus on training tactics but also on resistance. Assessing fatigue through this model could be the first step towards determining the adequate intensity of training sessions in order to improve the resistance of each player, influencing also their performance.

4.7 REFERENCES

1. **Stubbs, Ray.** *The Sports Book.* s.l. : Dorling Kindersley Ltd., 2011. p. 363.

2. *The competitive demands of elite male rink hockey.* **Yagüe, P.L., et al.** 2013, Biology of Sport, Vol. 30, pp. 195-199.

3. *An analysis of Competitive Activity in Professional Rink Hockey Players.* **Merino Tantiña , J., Baiget Vidal, E. and Peña López, J.** 2, 2014, Kronos Journal, Vol. 13.

4. **Amerique, Québec.** *Sports: The Complete Visual Reference.* 2005. p. 335.

5. *Measurement of fatigue in industries.* **Saito, Kazuo.** 1999, Industrial Health: National Institute of Occupational Safety and Health, pp. 134-142.

6. *Fatigue and Sport.* **Dal Monte, Antonio and Faina, Marcello.** 1, Rome : s.n., 2002, Functional Neurology, Vol. 17, pp. 7-10.

7. *Is part of the mystery surrounding fatigue complicated by context?* **Abbiss,**

Chris and Laursen, Paul. 2007, Journal of Science and Medicine in Sport, Vol. 10, pp. 277-279.

8. *Psychophysical bases of perceived exertion.* **Borg, Gunnar A.V.** 5, 1982, Medicine and Science in Sports and Exercise, Vol. 15, pp. 377-381.

9. *Psychophysical scaling with applications in physical work and the perception of exertion.* **Borg, Gunnar.** 1, 1990, Scand J Work Environ Health, Vol. 16, pp. 55-58.

10. *A comparison between three rating scales for perceived exertion and two different work test.* **Borg, E. and Kaijser, L.** 1, February 2006, Scandinavian Journal of Medicine and Science in Sports, Vol. 16.

11. *Physical performance and perceived exertion.* **Borg, Gunnar.** Lund : s.n., 1962, Studia psychologica et paedagogica: Investigationes, Vol. 11, pp. 5-60.

12. *The ingestible telemetric body core temperature sensor: a review of validity and exercise applications.* **Chin Leong Lim and Christopher Byrne.** 2007, British Journal of Sports Medicine , Vol. 41, pp. 126-133.

13. *Thermal Responses in Football and Cross-Country Athletes During Their Respective Practices in a Hot Environment.* **Fowkes Godek, Sandra, Godek, Joseph J. and Bartolozzi, Arthur R.** 3, 2004, Journal of Athletic Training, Vol. 39, pp. 235-240.

14. *Thermoregulatory observations in soccer match play: professional and recreational level applications using an intestinal pill system to measure core temperature.* **Edwards, A. M. and Clark, N. A.** 2006, Journal of Sports Medicine, Vol. 40, pp. 133-138.

15. *Core Temperature and Percentage of Dehydration in Professional Football Linemen and Backs During Preseason Practices.* **Fowkes Godek , Sandra, et al.** 1, 2006, Journal of Athletic Training, Vol. 41, pp. 8-17.

16. *Core temperature and hydration status during an Ironman triathlon.* **Laursen, P.B., et al.** 2006, British Journal of Sports Medicine , Vol. 40, pp. 320-325.

17. *The role of aerobic capacity in highintensity intermittent efforts in icehockey.* **Stanula, A., et al.** July 2014, Biology of Sport, Vol. 31, pp. 193-199.

18. **Vaz, V.P.S.** Especialização Desportiva em Jovens Hoquitas Masculinos. Estudo do jovem atleta, do processo de selecção e da estrutura do rendimento. [PhD Thesis]. Coimbra, Portugal : s.n., April 2016.

19. *Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity.* **Scherr, et al..** 2012, European Journal of Applied Physiology, Vol. 113, pp. 147-155.

20. *The effects of fatigue on decision making and shooting skill performance in water polo players.* **Royal, Kylie A., et al.** 8, August 2006, Jounar of Sports Sciences, Vol. 24, pp. 807-815.

21. *Hockey sobre patines: niveles de frecuencia cardíaca y lactacidemia en competición y entrenamiento.* **Blanco,**

A., Enseñat, A. and Balagué, N. 1994, Apunts: Educación física y deportes, Vol. 36, pp. 26-36.

22. *Age-Predicted Maximal Heart Rate Revisited.* **Hirofumi Tanaka, Kevin D. Monahan and Douglas R. Seals.** 1, 2001, Journal of the American College of Cardiology, Vol. 37, pp. 153-156.

23. *Energy demands in competitive soccer.* **Bangsbo, Jens.** 1994, Journal of Sports Sciences, Vol. 12, pp. 5-12.

24. *Relationship between subjectively perceived exertion and objective loading in trained athletes and non-athletes.* **Kovářová, L., et al.,** 2015.

5. FINAL REMARKS

Through this study, it was possible to determine a model that allowed the prediction of RPE values with a very good adjust (R^2=0,96) by using objective (physiological) indicators of fatigue such as LAC and CT. However, as already established, this study has limitations because of the type and conditions of the cohort.

Part of these limitations can be clearly observed when studying the outlier Player N°9. While there were found three outliers (Players N°1, 2 and 9), two of them were defined due to protocol deviations and only Player N°9 was considered an outlier because his tests results were a reflect of his particular condition.

Player N°9's lack of appropriate resting, eating and hydration in the last three days caused him to reach his maximum fatigue level sooner than the rest of the players. Nevertheless, it was observed that despite his fatigue level increased rapidly, his performance, according to shooting accuracy, was not affected until the last lap in which a breakpoint was observed. At this moment of maximum fatigue (level 10 in RPE Scale), Player N°9 was impaired of skating or shooting accurately due to his condition.

Outcomes, until the breaking point in the last lap, were consistent with the results obtained by Kylie A. Royal et al. [24]. In their study about water polo players, shooting accuracy and velocity of the ball were not affected by the increase of fatigue levels. The breakpoint that Player N°9 suffered can lead to a further study that allows to identify the point from which a person is not able to continue performing a task, without compromising the goal.

On the other hand, decreased skill proficiency between pre-test and the end of it in high-fatigue conditions could be observed during this test, as well as in the experience conducted by Kylie A. Royal et al. [24]. This skill proficiency decrease could be clearly observed in the present study, through the difficulties that the player had while skating and driving the ball (decrease of technique).

The entire cohort presented the same characteristics regarding this fact: those who missed shots in low-fatigue conditions also missed in high-fatigue conditions; and those who shot accurately in low-fatigue conditions also did in high-fatigue ones (except from the breaking point observed in Player N°9 in the last lap). That is to say, performance was not affected by incremental fatigue when assessed by shooting accuracy, but it was affected when contemplating their skills proficiency, in accordance with the results presented by Kylie A. Royal et al. [24].

According to the previous statements it can be concluded that, despite fatigue increments, player's objective of shooting accurately was not impaired. Following this, in the so called safety-sensitive professions it could be expected that although workers may suffer a performance decrease, they still might be able to perform effectively, meeting their goals. However, this is a statement that cannot be made without further study. It is necessary to consider other psychological factors, because of the nature of these professions in which performance is closely linked to third-parties safety.

Player N°9 was not considered as part of the sample used to determine the model, mainly because he did not rest well nor ate properly. This affected notoriously his performance, not only physically but mentally, as he rapidly reached a 10 RPE level of fatigue in the 7th lap, when the rest did in the 10th-12th laps. Therefore, these results show the need for further study that includes other factors, which could influence fatigue more severely than the mainly physical fatigue addressed in this research. Among these factors, it should be considered: sleep deprivation, mental exertion, incomplete recovery, and even emotional predisposition [1]. Consequences of fatigue affect each individual differently, depending on their emotional predisposition, and are often exacerbated under distress. Sometimes, causes can be purely psychological, which is the main cause of mental fatigue [3].

Fatigue impairs work ability primarily by increasing workers' time to accomplish tasks and impeding their concentration [4]. So, mental fatigue should also be studied when contemplating safety-sensitive professions, as stated for nurses, that may be particularly susceptible to multiple dimensions of fatigue, and their performance can affect patient safety directly [31].

Finally, it is important in the assessment of fatigue to make not only physiological and psychological measurements, but also relate the findings to several factors which influence fatigue. This would make it possible to evaluate the grade of the obtained change in view of undesirable negative effects on health and well-being. In conclusion, fatigue should be evaluated by a multidisciplinary approach [1].

As previously stated, the multiple regression model presented can predict fatigue objectively in rink hockey players. Despite being related to Borg's RPE Scale that integrates psychophysical factors, this study assessed mostly physical fatigue of subjects. Taking this into account, the model presented in this study could also be implemented to predict fatigue in professions that are mainly physical (construction carpenters, structural workers, machine operators, etc.), since physiological parameters were taken into account to assess physical exertion. This could be important in matter of prevention, as this tool can determine worker fatigue avoiding accidents when it reaches levels in which they cannot perform safely. It could help to determine whether and when an adequate shift or resting time should be incorporated.

However, when considering safety-sensitive professions, additional variables should be included because of the nature of these jobs. In this way, this model could be the basis to study fatigue in safety-sensitive related occupations, by adding the other aforementioned psychological variables to the model that already allows to predict psychophysical fatigue. That is to say, variables such as sleep deprivation and incomplete recovery should be included to complement the present model, in order to allow the multidisciplinary approach that the complexity of fatigue assessment and these professions requires.

6. REFERENCES

1. *Measurement of fatigue in industries.* **Saito, Kazuo.** 1999, Industrial Health: National Institute of Occupational Safety and Health, págs. 134-142.

2. *Worker fatigue: Managing concerns in rapid renewal highway construction projects.* **Hallowell, Matthew.** 2010, Professional Safety.

3. *Causes and Consequences of Occupational Fatigue: Meta-Analysis and Systems Model.* **Techera, Ulises, et al.** 10, August de 2016, Journal of Occupational and Environmental Medicine, Vol. 20.

4. *Fatigue in the U.S. Workforce: Prevalence and Implications for Lost Productive Work Time.* **Judith A. Ricci, et al.** 1, January de 2007, Journal of Occupational and Environmental Medicine, Vol. 49.

5. The Accident Compensation Corporation (ACC). [En línea] http://www.acc.co.nz/preventing-injuries/at-work/occupational-health/PI00083.

6. National Sleep Foundation. 2010 Sleep in America poll: summary of findings. [En línea] https://sleepfoundation.org/sites/default/files/nsaw/NSF%20Sleep%20in%20%20 America%20Poll%20-%20Summary%20of%20Findings%20.pdf.

7. *Long Working Hours and Subjective Fatigue Symptoms.* **Jungsun Park, et al.** 2001, Industrial Health, Vol. 39, págs. 250-254.

8. **Paoli , Pascal and Merllié, Damien .** *Third European survey on working conditions.* EUROPEAN FOUNDATION for the Improvement of Living and Working Conditions. 2000.

9. *Fatigue Risk Management in the Workplace.* **Lerman, Steven E., et al.** 2, February de 2012, Journal of Occupational and Environmental Medicine, Vol. 54.

10. *Health effects of shift work and extended hours of work.* **Harrington, J.M.** 2001, Occupational and Environmental Medicine, Vol. 58, págs. 68-72.

11. *Effects of sleep loss and sustained cognitive performance during a command and control simulation.* **Angus, Robert G. and Heslegrave, Ronald J.** 1985, Behavior Research Methods, Instruments and Computers, Vol. 17, págs. 55-67.

12. *Psychosocial Work Stressors, Work Fatigue, and Musculoskeletal Disorders: Comparison between Emergency and Critical Care Nurses in Brunei Public Hospitals*. **Hanif Abdul Rahman, Khadizah Abdul-Mumin and Lin Naing**. March 2017, Asian Nursing Research, Vol 11 (1), págs. 13-18.

13. *Hospital Staff Nurses' Work Hours, Meal Periods, and Rest Breaks.* **Amy Witkoski and Victoria Vaughan Dickson**. 2010, American Association of Occupational Health Nursing Journal, Vol 58 (11), págs. 489-497

14. *Fighting fire and fatigue: sleep quantity and quality during multi-day wildfire suppression*. **Grace E. Vincent, Brad Aisbett, Sarah J. Hall and Sally A. Ferguson**. 2016, Ergonomics, Vol. 59 (7), págs. 932-940.

15. *The Cumulative Cost of Additional Wakefulness: Dose-response Effects on Neurobehavioral Functions and Sleep Physiology from Chronic Sleep Restriction and Total Sleep Deprivation.* **Van Dongen, H. P. A., G. Maislin, J. M. Mullington and D. F. Dinges**. 2003, Sleep, Vol. 26 (2), págs.117–126.

16. *Shift Work, Safety and Productivity*. **Folkard, S. and P. Tucker**. April 2003, Occupational Medicine, Vol. 53 (2), págs. 95–10.1

17. *Determining fitness to work at safety-sensitive jobs.* **Martin, Steve.** January 2010, British Columbia Medical Journal, Vol. 52, pág. 48.

18. *Psychophysical bases of perceived exertion.* **Borg, Gunnar A.V.** 5, 1982, Medicine and Science in Sports and Exercise, Vol. 15, págs. 377-381.

19. *Psychophysical scaling with applications in physical work and the perception of exertion.* **Borg, Gunnar.** 1990, Scand J Work Environ Health, Vol. 16, págs. 55-80.

20. *A comparison between three rating scales for perceived exertion and two different work test.* **Borg, E. and Kaijser, L.** February de 2006, Scandinavian Journal of Medicine and Science in Sports, Vol. 16.

21. *Physical performance and perceived exertion.* **Borg, Gunnar.** Lund : s.n., 1962, Studia psychologica et paedagogica: Investigationes, Vol. 11, págs. 5-60.

22. *Use of Ratings of Perceived Exertion in Sports.* **Eston, Roger .** 2012, International Journal of Sports Physiology and Performance, Vol. 7, págs. 175-182.

23. *Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity.* **Scherr, et al.** 2012, European Journal of Applied Physiology, Vol. 113, págs. 147-155.

24. *The effects of fatigue on decision making and shooting skill performance in water polo players.* **Royal, Kylie A., et al.** 8, August de 2006, Jounar of Sports Sciences, Vol. 24, págs. 807-815.

25. *Hockey sobre patines: niveles de frecuencia cardíaca y lactacidemia en competición y entrenamiento.* **Blanco, A., Enseñat, A. and Balagué, N.** 1994, Apunts: Educación física y deportes, Vol. 36, págs. 26-36.

26. *Thermal Responses in Football and Cross-Country Athletes During Their Respective Practices in a Hot Environment.* **Fowkes Godek, Sandra, Godek, Joseph J. and Bartolozzi, Arthur R.** 3, 2004, Journal of Athletic Training, Vol. 39, págs. 235-240.

27. *Thermoregulatory observations in soccer match play: professional and recreational level applications using an intestinal pill system to measure core temperature.* **Edwards, A. M. and Clark, N. A.** 2006, Journal of Sports Medicine, Vol. 40, págs. 133-138.

28. *Core Temperature and Percentage of Dehydration in Professional Football Linemen and Backs During Preseason Practices.* **Fowkes Godek , Sandra, et. al.** 1, 2006, Journal of Athletic Training, Vol. 41, págs. 8-17.

29. *Core temperature and hydration status during an Ironman triathlon.* **Laursen, P.B., et al.** 2006, British Journal of Sports Medicine , Vol. 40, págs. 320-325.

30. *An analysis of Competitive Activity in Professional Rink Hockey Players.* **Merino Tantiña , J., Baiget Vidal, E. and Peña López, J.** 2, 2014, Kronos Journal, Vol. 13.

31. *Fatigue, performance and the work environment: a survey of registered nurses.* **Barker, Linsey M. and Nussbaum, Maury A. .** 6, 2011, Journal of Advanced Nursing, Vol. 67, págs. 1370-1382.